

EFFECT OF PLASTIC DEFORMATION ON SUPERCOOLED AUSTENITE DECOMPOSITION IN ADVANCED MULTIPHASE STEELS

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Presentation Outline

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Introduction

- Automotive steels evolution
- Quenching and Partitioning heat treatment

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Aim of the study

- Aim of the work
- Scope of the work

3

Materials and methods

- Thermodynamic approach and dilatometry
- Microstructural characterization techniques

4

Results

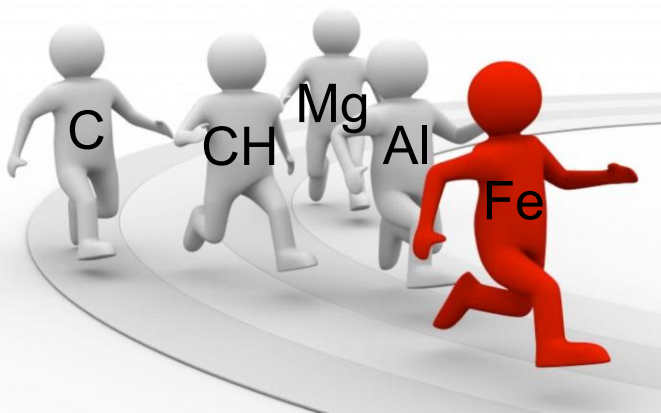
- Thermodynamic-kinetic calculations
- CCT - Continuous cooling transformations and deformation effects
- TTT - Time temperature transformation and deformation effects

5

Conclusions



Automotive steels



Continuous competition between steel, aluminium, magnesium and polymer materials



Driving force of development

Mechanical properties:

Strength is not a problem of modern steels

The problem is **ensuring high strength levels**
maintaining high fracture resistance and ductility



Applications:

- Sheets
- Plates
- **Forgings**
- Rods

- Mild steel
- High strength steel
- Very high strength steel
- Extra high strength steel
- Ultra high strength steel
- Aluminium

<https://www.carbodydesign.com/gallery/2015/12/volvo-reveals-s90-sedan/30/>

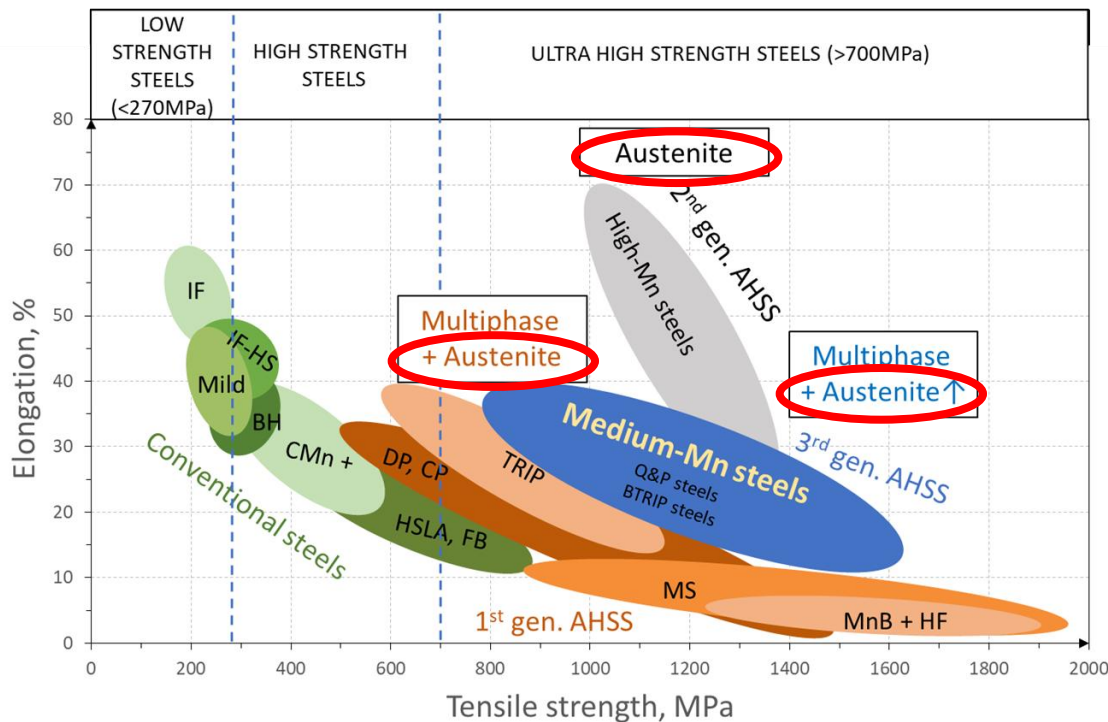
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„Banana curve”



Conventional deep drawing steels

High strength steels 1st gen.

High strength steels 2nd gen.

High strength steels 3rd gen.

What is one of the most important phases in automotive steels nowadays?

Austenite

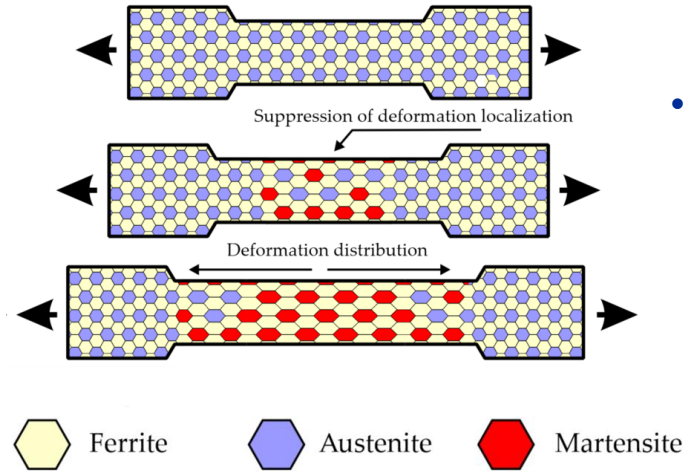
(or to be more precise:
Retained austenite)

And why is that so?

The role of retained austenite

Tensile strain

- Increase of strain hardening by SIMT
- Delay in a neck formation due to the **TRIP** effect
- Increase in plasticity



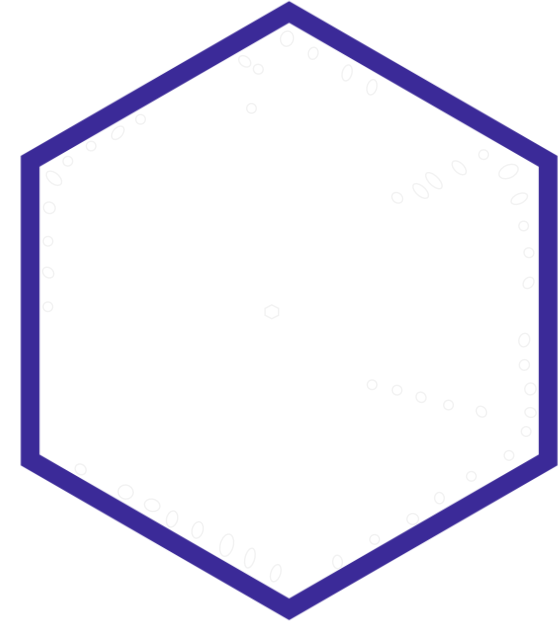
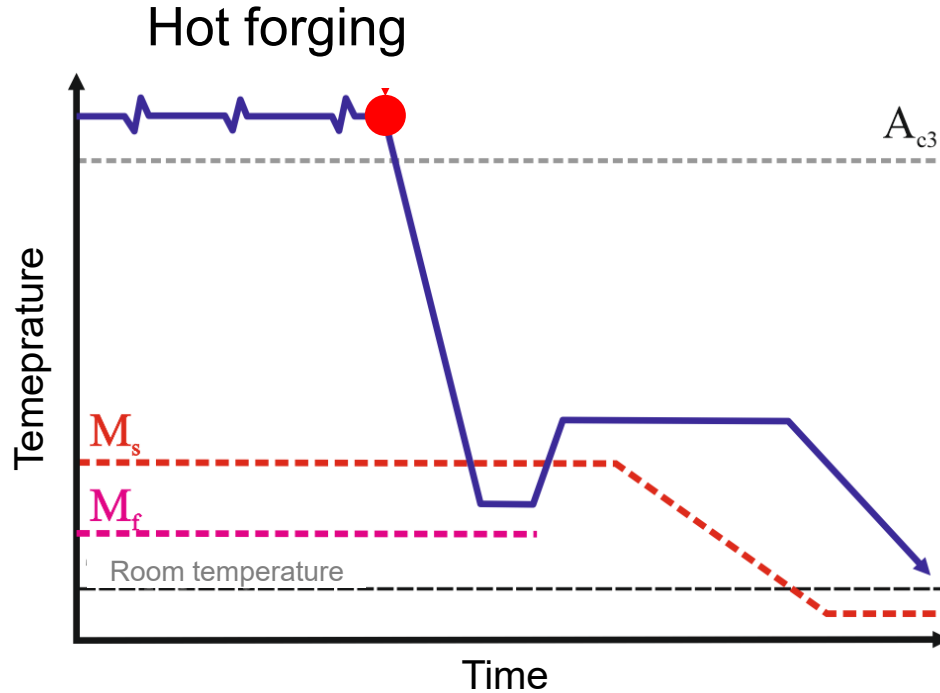
Fatigue

- Absorption of strain and inhibition of crack propagation by highly-ductile austenite

TRIP – Transformation Induced Plasticity

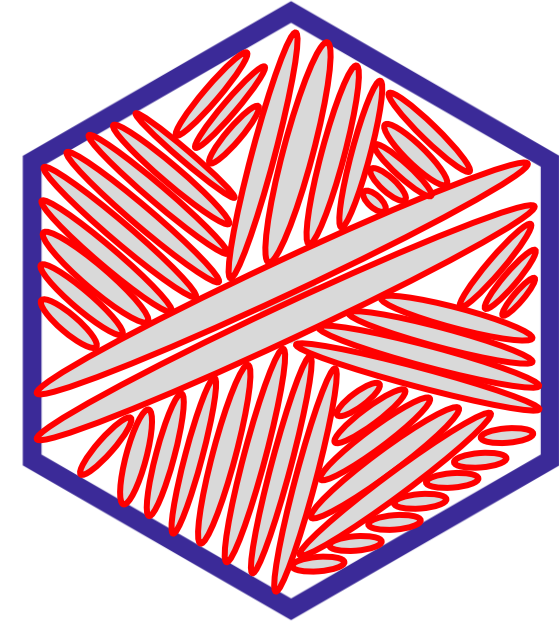
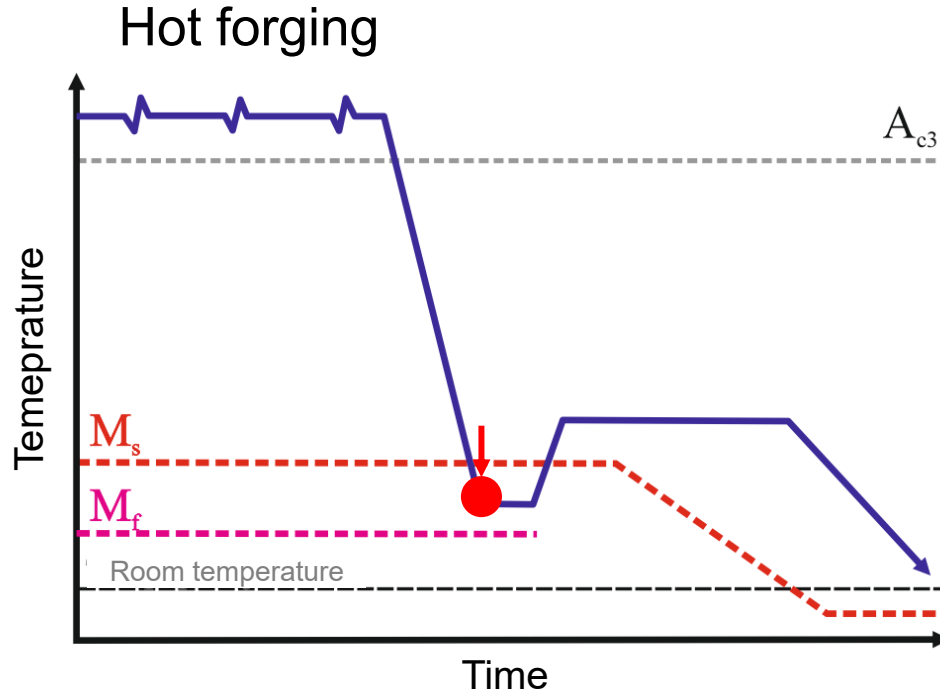
Quenching & Partitioning

	Austenite		Tempered martensite
	Martensite		Retained austenite



Quenching & Partitioning

	Austenite		Tempered martensite
	Martensite		Retained austenite

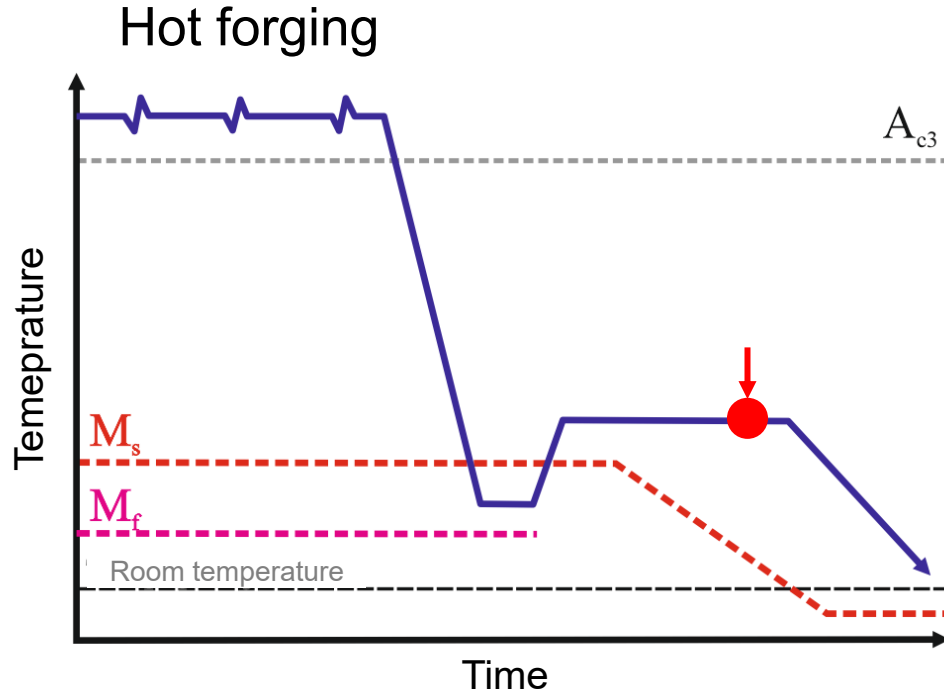


Austenite as thin laths / films

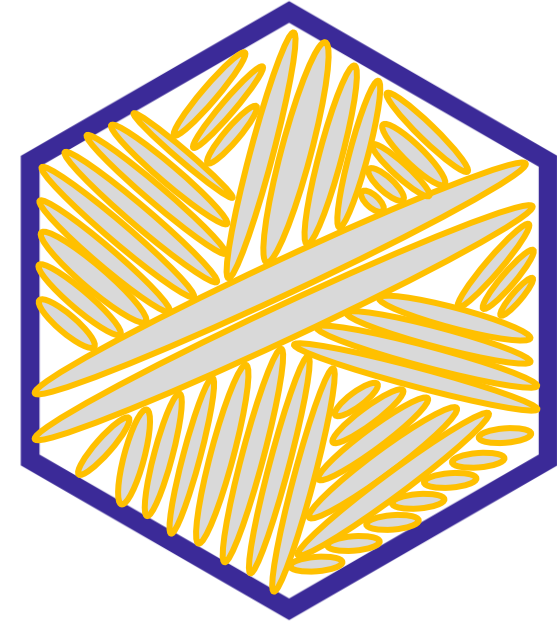
Quenching interrupted at an optimal temperature

Quenching & Partitioning

	Austenite		Tempered martensite
	Martensite		Retained austenite



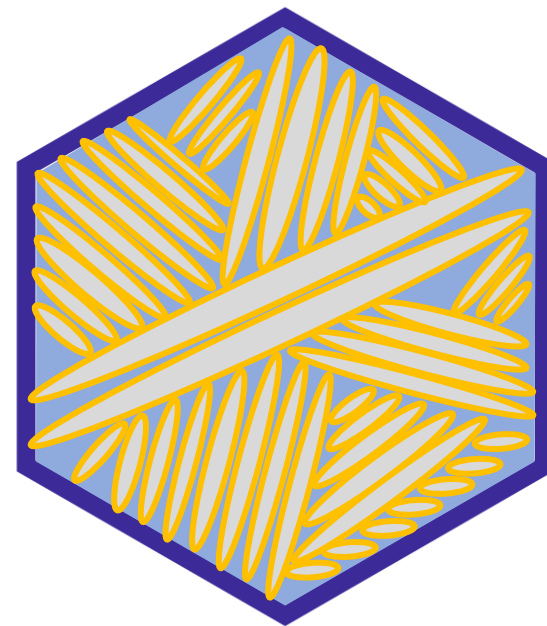
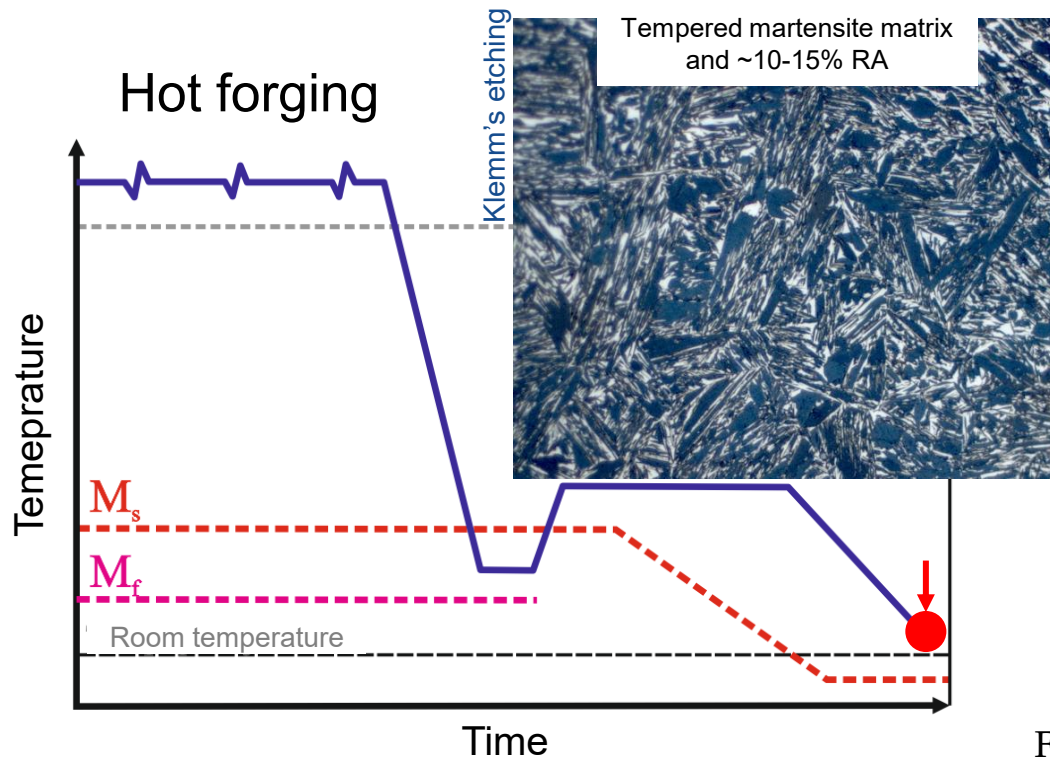
Quenching interrupted at an optimal temperature



Tempering of martensite
and stabilization of film-like austenite

Quenching & Partitioning

	Austenite		Tempered martensite
	Martensite		Retained austenite



Full stabilization of the remaining austenite

Quenching interrupted at an optimal temperature

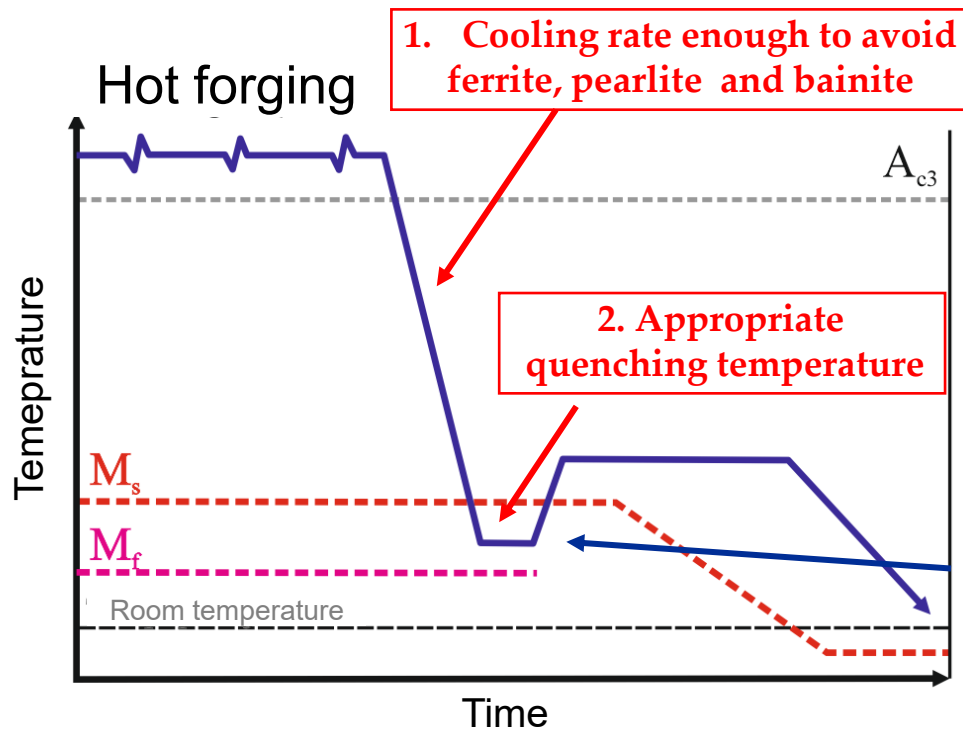
Aim of the study

Developing steels (**especially green steels**) made from **recycled scrap** will contain residual elements like **Mo and especially Cu**, which affect significantly critical temperatures, the decomposition of austenite / deformed austenite.

The present work aims at analyzing the effect of plastic deformation and cooling conditions (**continuous / isothermal**) on phase transformation behavior of novel Mo- and Cu-added medium-Mn steels subjected to Quenching and Partitioning heat treatment.



Design of Quenching and Partitioning



Optimization of QP parameters based on the DCCT and DTTT diagrams

CCT / DCCT_{continuous}

TTT / DTTT_{isothermal}

3. Kinetics of the bainitic transformation below the M_s temperature



Investigated material

Relatively low carbon content – good machinability

Solid solution strengthening and improvement of hot ductility

Grain refinement

Wt.%	C	Mn	Si	Al	Mo	Cu	Nb
O1	0.18	4.00	0.52	0.76	-	-	0.05
O2	0.17	4.02	0.51	0.75	0.30	-	0.05
O3	0.17	4.10	0.52	0.79	0.30	1.04	0.05

Increased Mn content – to increase the stability of retained austenite (RA)

Addition of Al and Si to prevent carbide precipitation

scrap recycling residual element



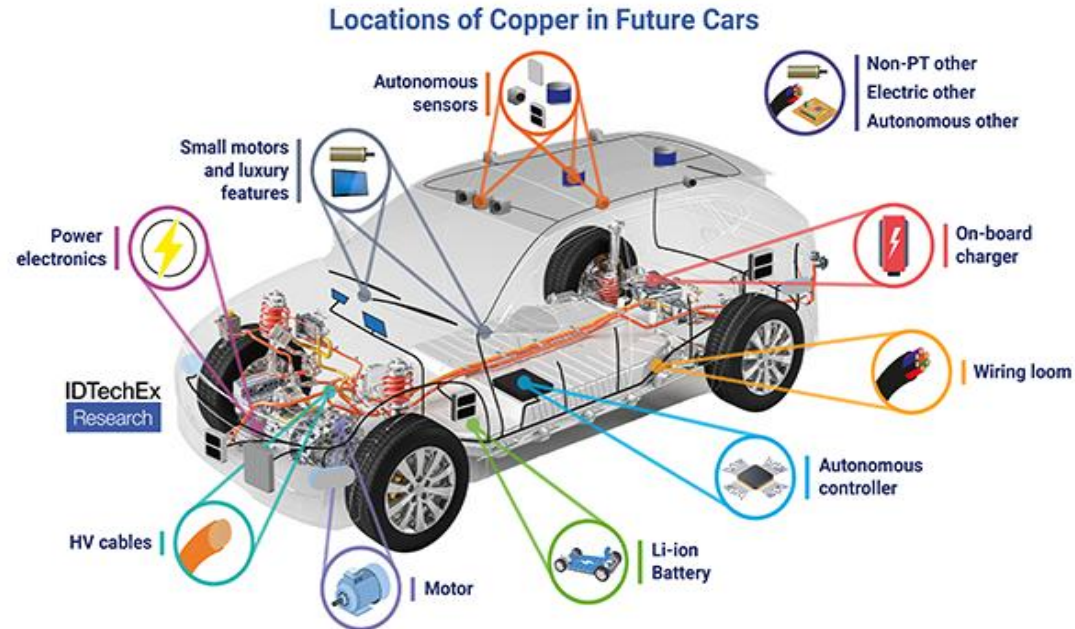
Contaminated steel scrap elements:

Cr, Mo, Ni, Cu, Sn

Sources of the elements:

- Shredder scrap from used cars
- Household appliances
- Small electric motors
- Coatings (food cans, etc.)
- Solder

Electric vehicles contain more copper

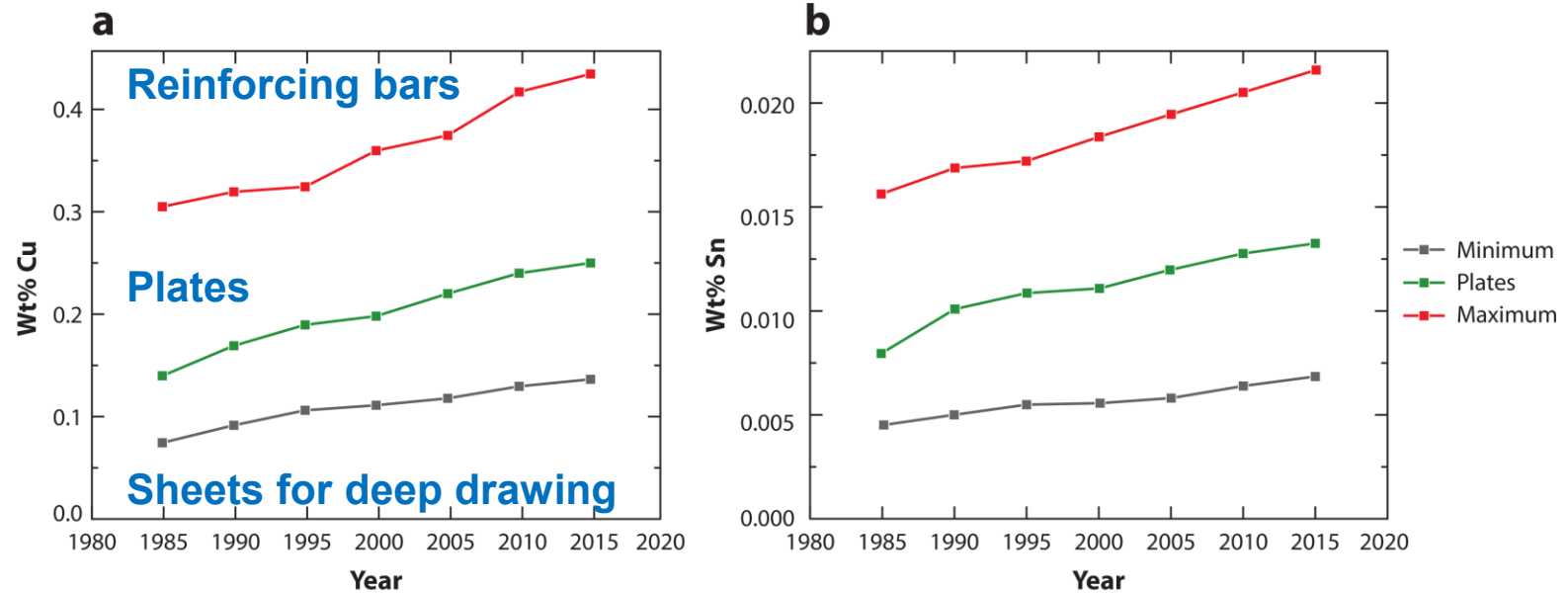


<https://www.greencarcongress.com/2023/12/20231214-copper.html>



Steel scrap elements:

Increase in Cu and Sn contents in steels



<https://www.annualreviews.org/content/journals/10.1146/annurev-matsci-080222-123648#right-ref-B116>



Methodology

Thermodynamic and
thermodynamic-kinetic
calculations



JMatPro
ver. 14.1

- Equilibrium diagrams
 - CCT diagram
 - TTT diagram

Dilatometry



- Determination of Ac1, Ac3, Ms and Mf temperatures
 - CCT diagram
 - TTT diagram

Post heat-treatment
material's
characterization

- Light microscopy
 - SEM, EBSD
 - Vickers hardness
-
- Phase composition
 - Hardness

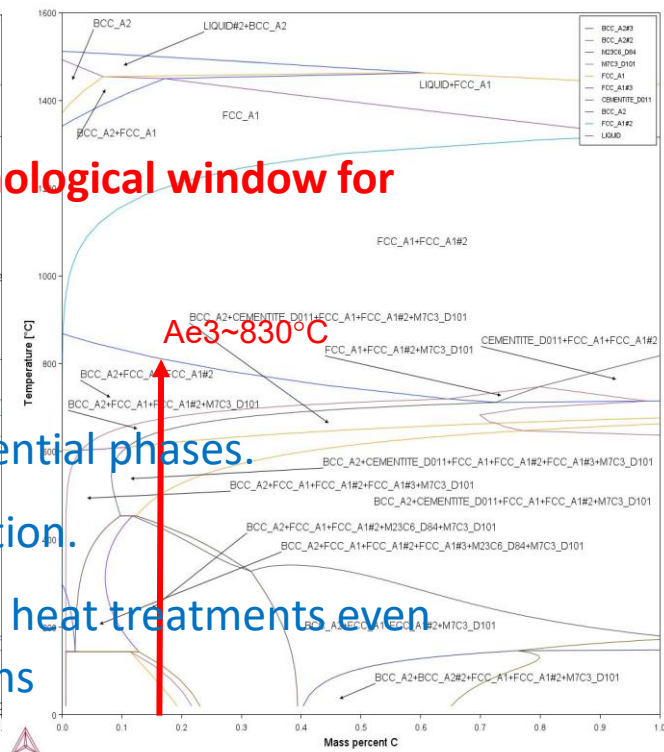
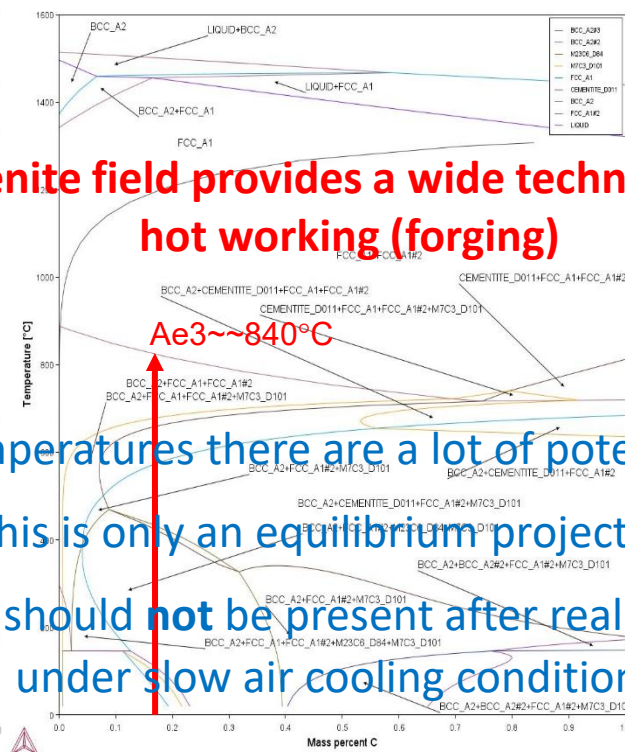
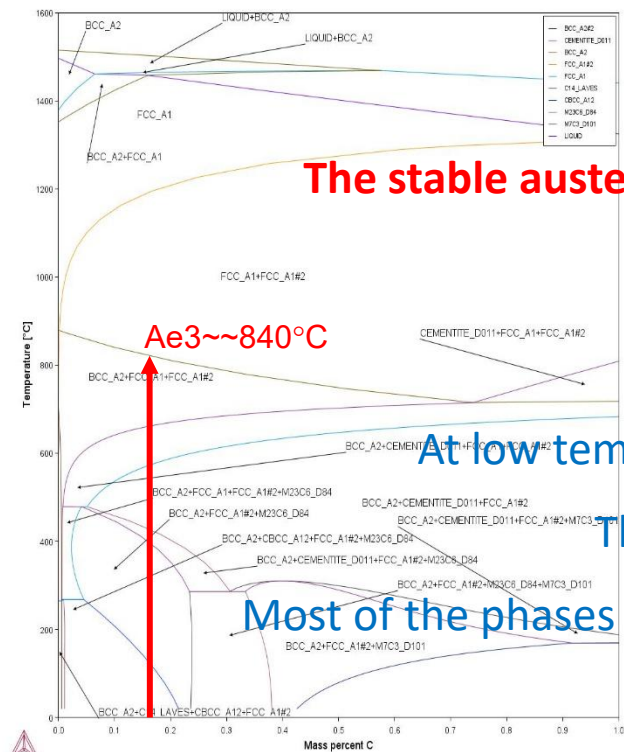


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Pseudo-binary phase diagrams

Mo

Mo+Cu



The stable austenite field provides a wide technological window for hot working (forging)

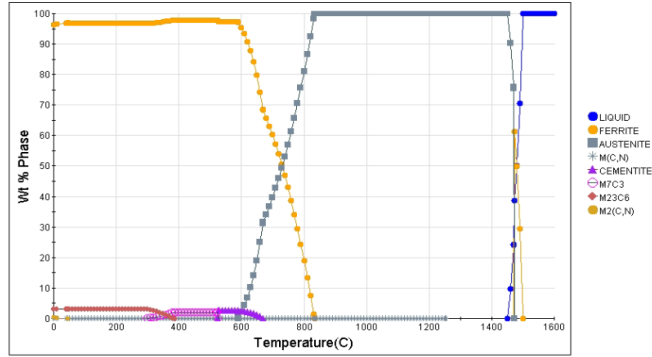
At low temperatures there are a lot of potential phases.

This is only an equilibrium projection.

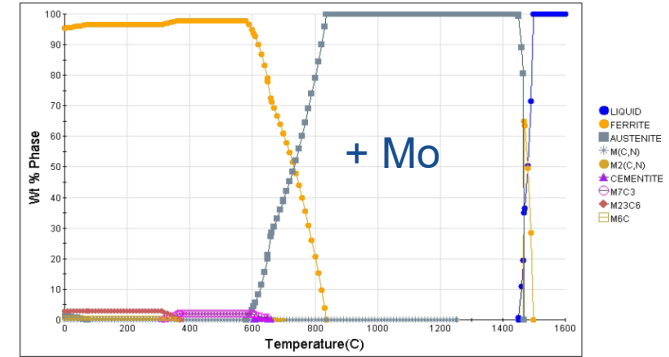
Most of the phases should not be present after real heat treatments even under slow air cooling conditions

Phase evolution – JMatPro

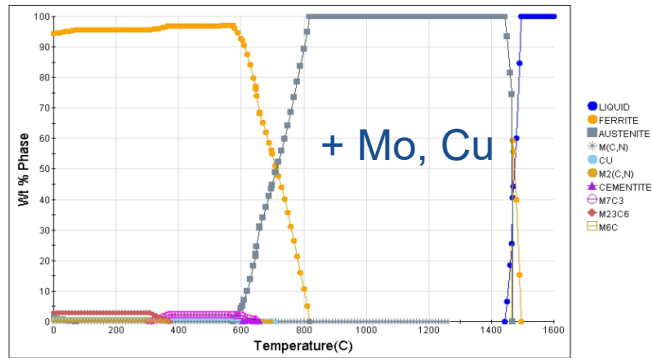
Fe-0.75Al-4Mn-0.05Nb-0.52Si-0.18C wt(%)



Fe-0.75Al-4.1Mn-0.3Mo-0.053Nb-0.51Si-0.17C wt(%)

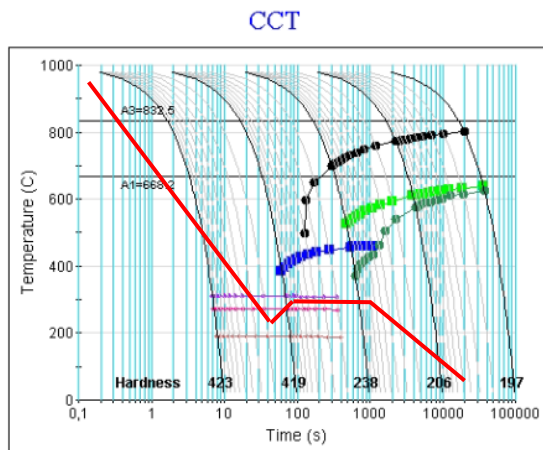


Fe-0.79Al-1.04Cu-4.1Mn-0.3Mo-0.053Nb-0.51Si-0.175C wt(%)

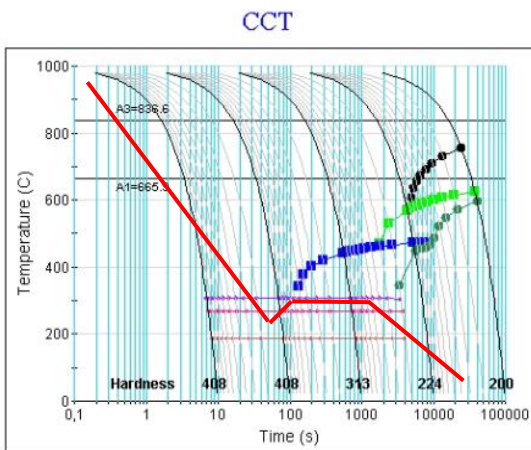


Wt. %	C	Mn	Si	Al	Mo	Cu	Ac1	Ac3
O1	0.18	4.00	0.52	0.76	-	-	588	832
O2	0.17	4.02	0.51	0.75	0.30	-	579	836
O3	0.17	4.10	0.52	0.79	0.30	1.04	573	818

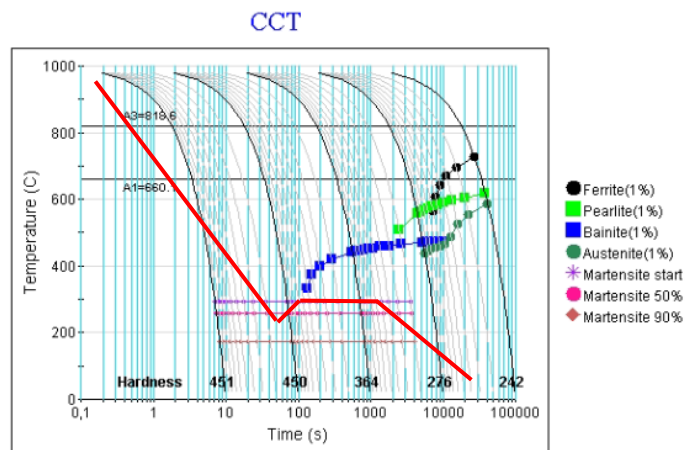
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Austenitisation temperature (C) : 1000.0
Grain size : 30.0 microns



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Austenitisation temperature (C) : 1000.0
Grain size : 30.0 microns

+ Mo

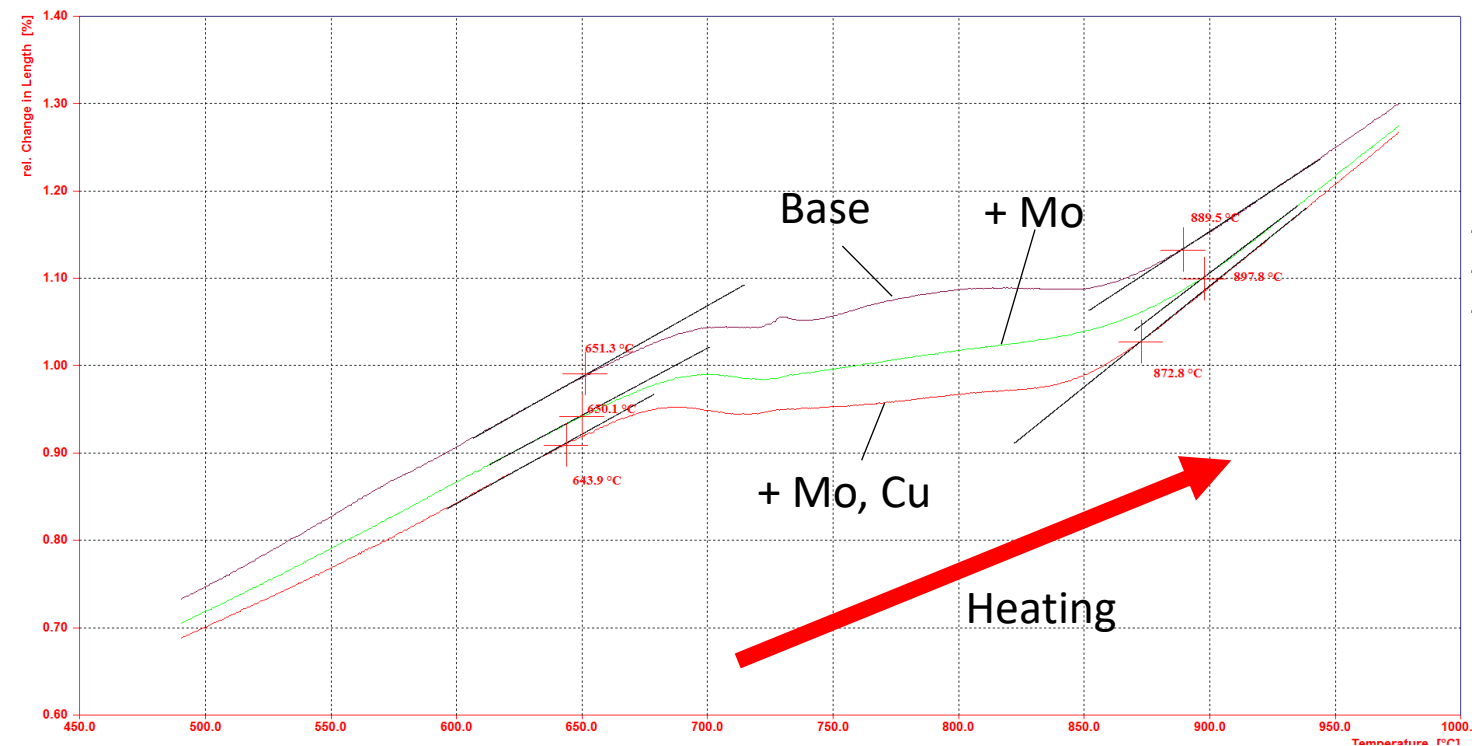
+ Mo, Cu

Quenching and Partitioning is required to produce **~80-85% of martensite** and the rest of **austenite (~ 20%) should be enriched in carbon** during the partitioning step



Dilatometric heating curves – 200 °C/h

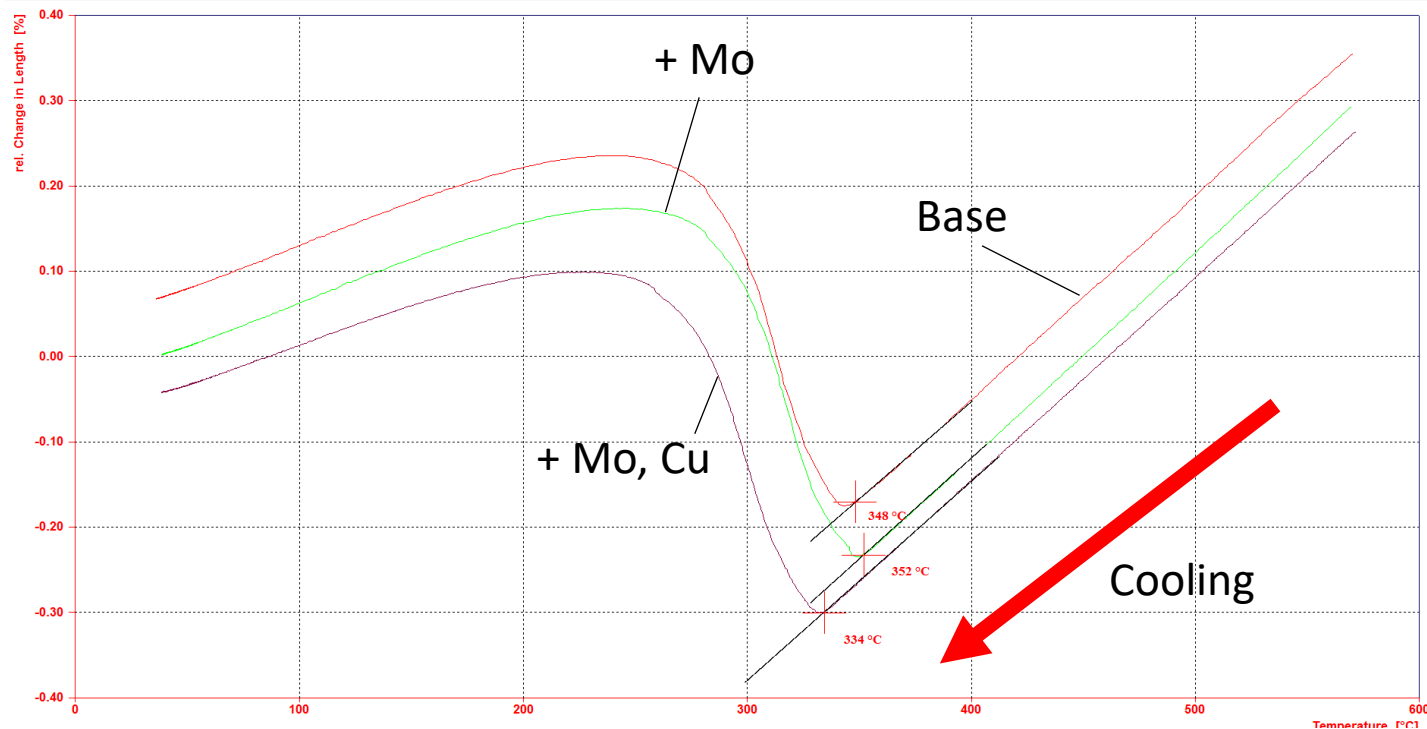
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O2	0.17	4.02	0.51	0.75	0.30	-
O3	0.17	4.10	0.52	0.79	0.30	1.04



Wt.%	Ac1	Ac3
Base	651	889
+ Mo	650	898
+ Mo, Cu	644	873

Dilatometric cooling curves – 60 °C/s

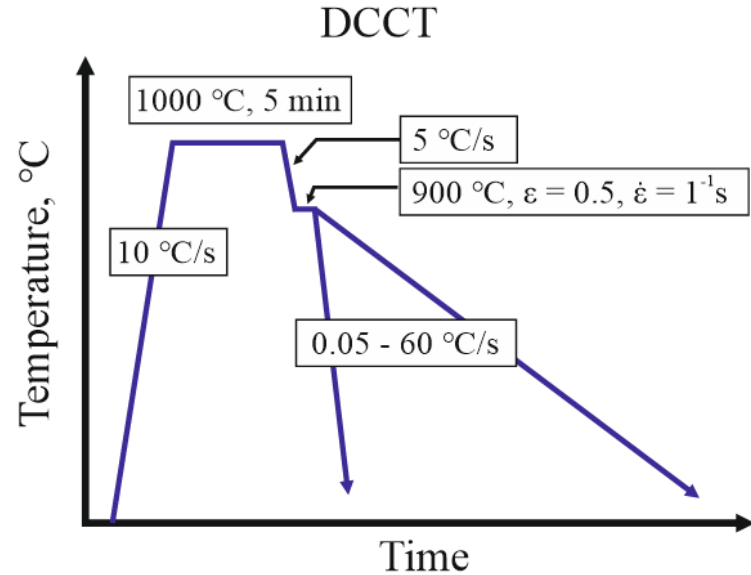
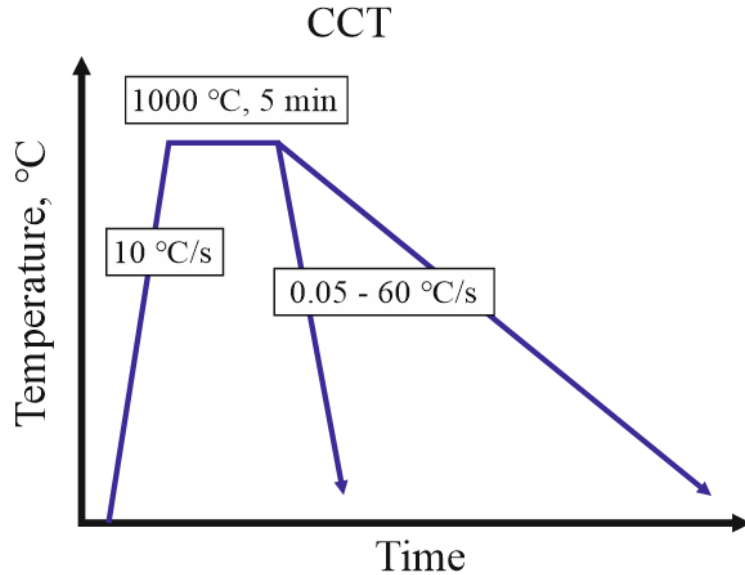
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O2	0.17	4.02	0.51	0.75	0.30	-
O3	0.17	4.10	0.52	0.79	0.30	1.04



Wt.%	Ms	Mf
Base	351	186
+ Mo	351	169
+ Mo, Cu	335	167

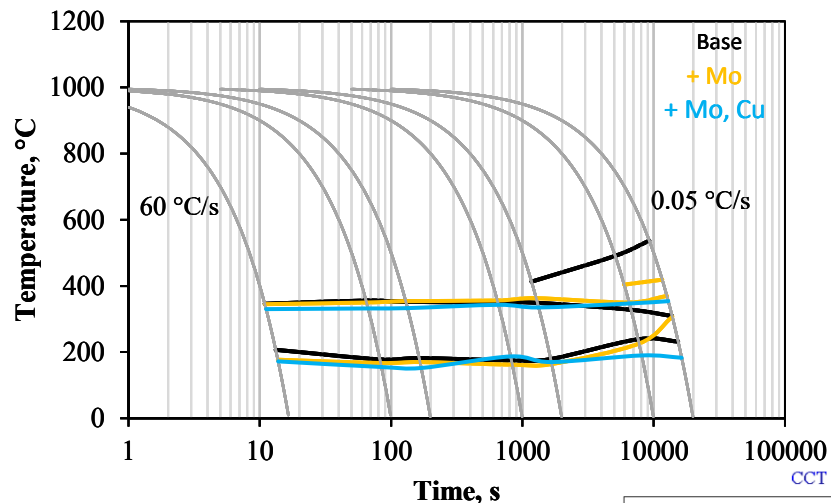
CCT parameters

Wt.%	C	Mn	Si	Al	Mo	Cu
O1	0.18	4.00	0.52	0.76	-	-
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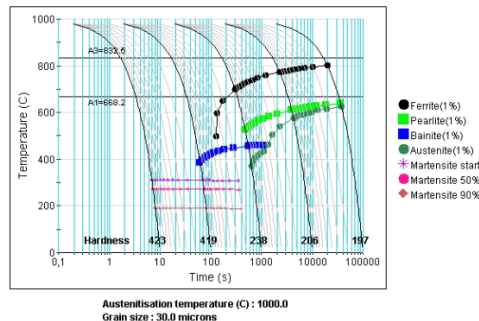


CCT - dilatometry

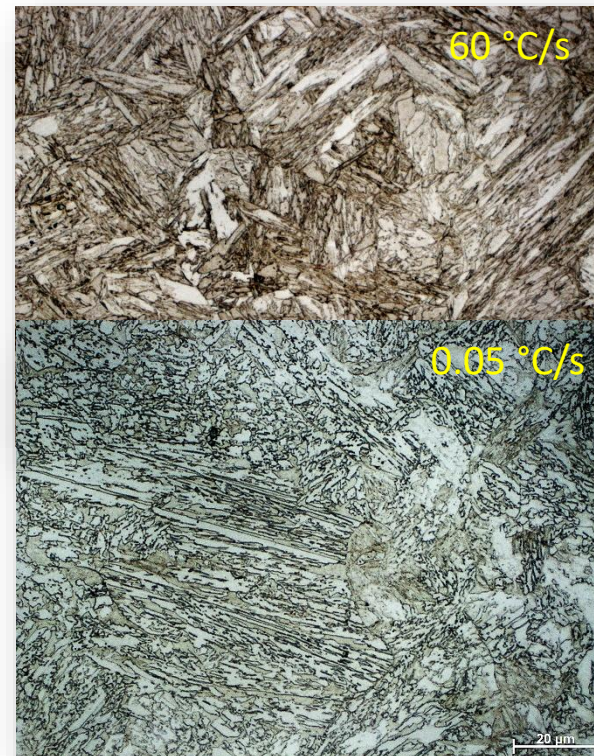
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O2	0.17	4.02	0.51	0.75	0.30	-
O3	0.17	4.10	0.52	0.79	0.30	1.04



- Significantly increased hardenability in comparison to simulations
- The presence of bainitic transformation only at cooling rates $< 0.5 \text{ °C/s}$



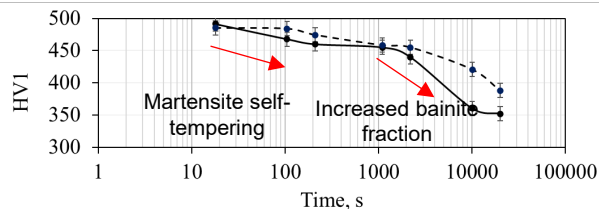
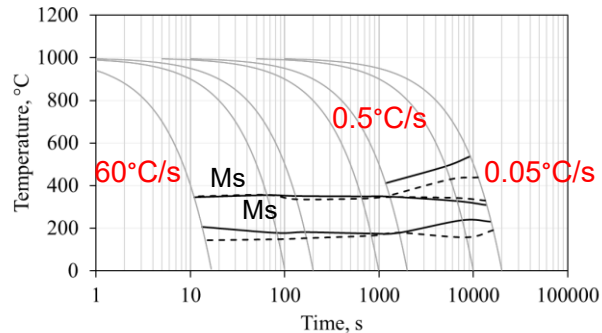
Base



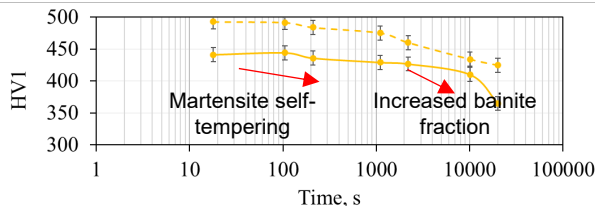
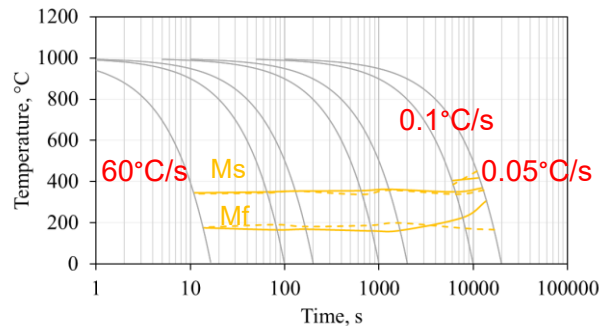
CCT vs. DCCT

— CCT - - - DCCT

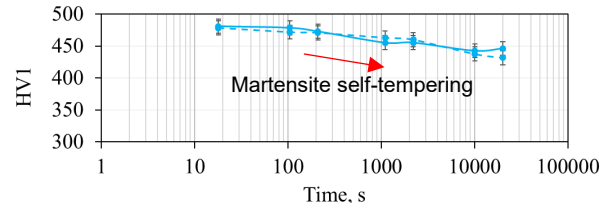
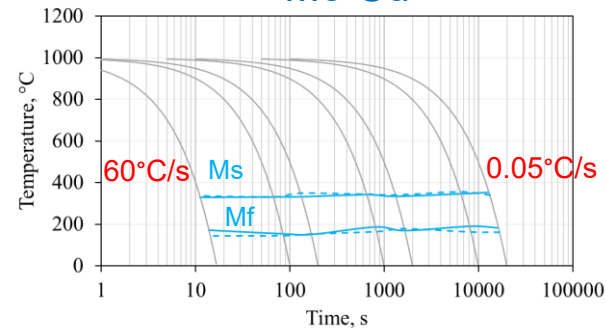
Base



Mo



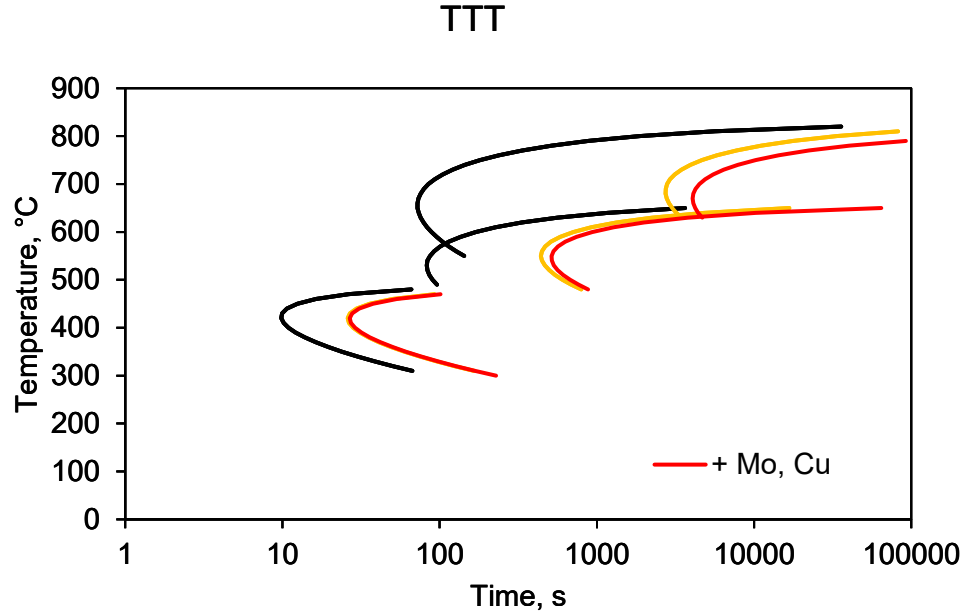
Mo Cu



- The same structural constituents
- **Plastic deformation delays the bainite formation** in the base steel
- High hardenability – ease of producing martensite even in air cooling

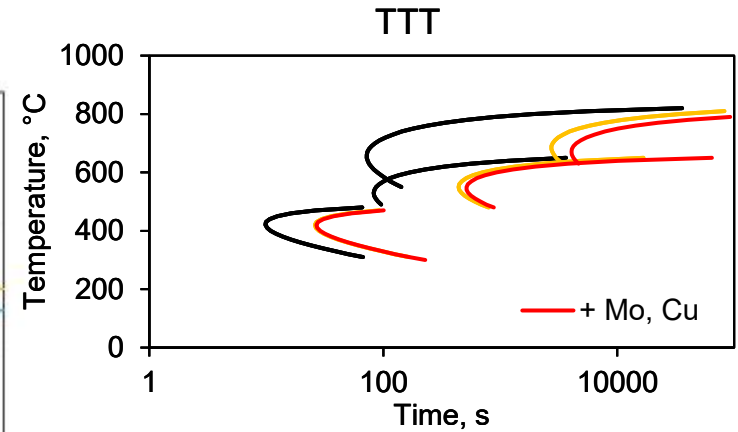
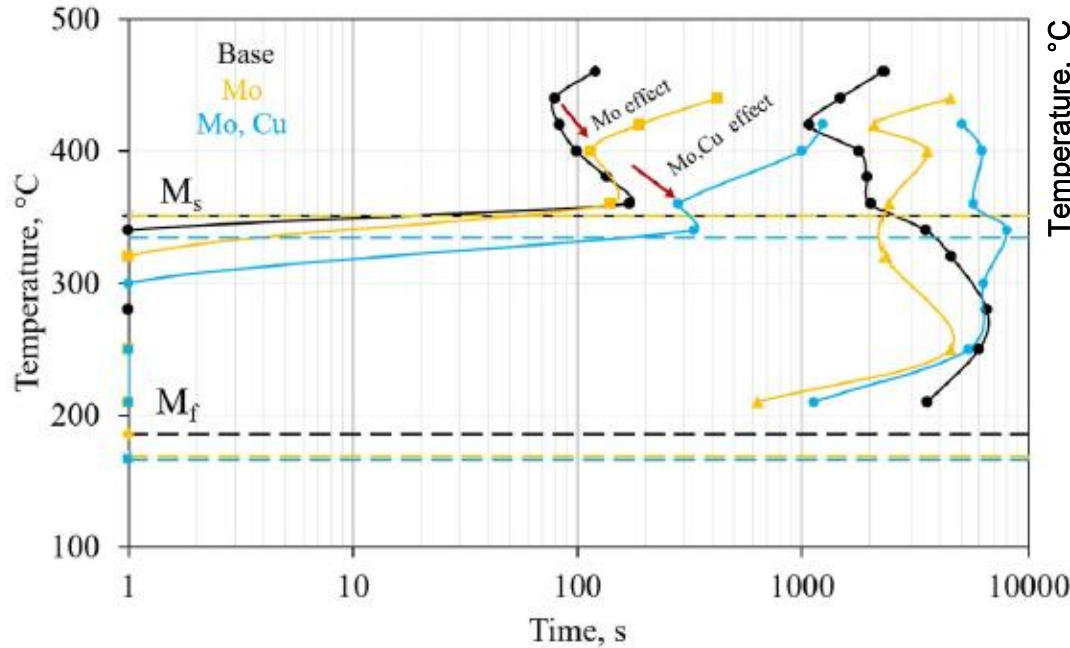
TTT – isothermal calculations

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O1	0.18	4.00	0.52	0.76	-	-	588	832
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O3	0.17	4.10	0.52	0.79	0.30	1.04	573	818



- Mo and Cu increase hardenability
- It should be possible to produce martensitic matrix even for air cooling conditions

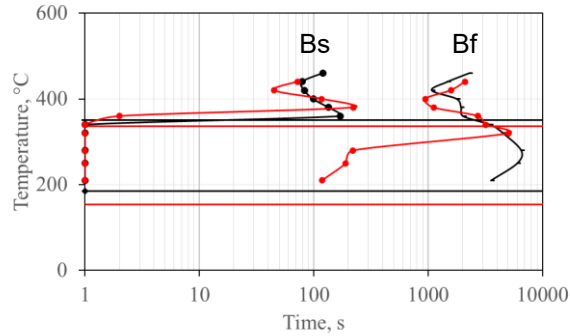
TTT – isothermal dilatometry



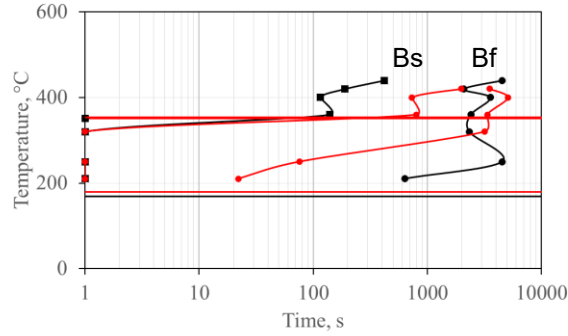
- The bainitic transformation is delayed and shifted to lower temperatures in Mo and Mo-Cu-containing steels
- **The bainitic transformation is delayed compared to JMatPro simulations**

TTT vs. DTTT

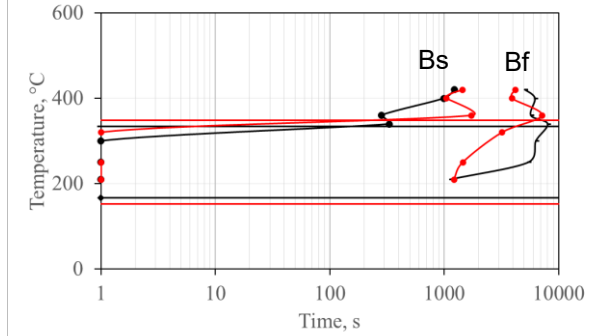
Base



Mo



Mo Cu



- The plastic deformation delays the bainitic transformation in Mo and Mo-Cu steels (mechanical stabilization of austenite by increased dislocation density and Mo and Cu strengthening)

Conclusions

	Ac1		Ac3		Ms		Mf	
	Calc.	Exp.	Calc.	Exp.	Calc.	Exp.	Calc.	Exp.
Base	588	652	832	889	308	351	190	186
Mo	579	653	836	898	305	351	186	169
MoCu	573	643	818	873	293	334	172	167

- The calculations reflect properly **only a tendency** of phase transformations, whereas there are significant differences in calculated critical temperatures and phase transformation temperature ranges
- The proposed chemical compositions are proper for producing martensitic steels with some portion of austenite without any ferrite, pearlite and (bainite)
- Mo and Cu delay the decomposition of austenite
- **Plastic deformation delays the bainite formation both under continuous and isothermal cooling conditions**

Can we rely on simulations ?

Simulations and thermodynamic calculations are very useful tools in optimizing the heat treatment schedules of modern steels. However, **their accuracy and reliability are still not high enough** to rely on them completely (**due to untypical Mn, Al, Cu contents**); it is still necessary to experimentally verify the obtained results.

Possible reasons of some differences:

- **inaccuracy of currently available models**
- **non-equilibrium conditions of the experiment**

Acknowledgements

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„Improving the fracture resistance of forging medium manganese steel under static, dynamic and cyclic loading conditions by means of fine-dispersed, partitioning-stabilized retained austenite”.



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